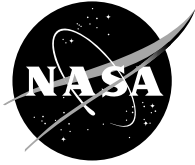


NASA/TM—2005-213973

IAC-05-A2.5.04



The Fluids and Combustion Facility: Enabling the Exploration of Space

Karen J. Weiland, Frank G. Gati, Myron E. Hill, and Terence F. O'Malley
Glenn Research Center, Cleveland, Ohio

Robert L. Zurawski
Johnson Space Center, Houston, Texas

The NASA STI Program Office . . . in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) Program Office plays a key part in helping NASA maintain this important role.

The NASA STI Program Office is operated by Langley Research Center, the Lead Center for NASA's scientific and technical information. The NASA STI Program Office provides access to the NASA STI Database, the largest collection of aeronautical and space science STI in the world. The Program Office is also NASA's institutional mechanism for disseminating the results of its research and development activities. These results are published by NASA in the NASA STI Report Series, which includes the following report types:

- **TECHNICAL PUBLICATION.** Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA's counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.
- **TECHNICAL MEMORANDUM.** Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.
- **CONTRACTOR REPORT.** Scientific and technical findings by NASA-sponsored contractors and grantees.

- **CONFERENCE PUBLICATION.** Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or cosponsored by NASA.
- **SPECIAL PUBLICATION.** Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.
- **TECHNICAL TRANSLATION.** English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services that complement the STI Program Office's diverse offerings include creating custom thesauri, building customized databases, organizing and publishing research results . . . even providing videos.

For more information about the NASA STI Program Office, see the following:

- Access the NASA STI Program Home Page at <http://www.sti.nasa.gov>
- E-mail your question via the Internet to help@sti.nasa.gov
- Fax your question to the NASA Access Help Desk at 301-621-0134
- Telephone the NASA Access Help Desk at 301-621-0390
- Write to:
NASA Access Help Desk
NASA Center for Aerospace Information
7121 Standard Drive
Hanover, MD 21076



The Fluids and Combustion Facility: Enabling the Exploration of Space

Karen J. Weiland, Frank G. Gati, Myron E. Hill, and Terence F. O'Malley
Glenn Research Center, Cleveland, Ohio

Robert L. Zurawski
Johnson Space Center, Houston, Texas

Prepared for the
56th International Astronautical Congress
sponsored by the Japan Aerospace Exploration Agency
Fukuoka, Japan, October 17–21, 2005

National Aeronautics and
Space Administration

Glenn Research Center

Acknowledgments

The NASA Headquarters Exploration Systems Mission Directorate and the Human Science and Research Technology Program provides funding for the FCF and support for combustion and fluid physics experiments. The authors gratefully acknowledge the FCF project team at ZIN Technologies, Inc. for their excellent work and contributions to develop the FCF.

Trade names or manufacturers' names are used in this report for identification only. This usage does not constitute an official endorsement, either expressed or implied, by the National Aeronautics and Space Administration.

Available from

NASA Center for Aerospace Information
7121 Standard Drive
Hanover, MD 21076

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22100

Available electronically at <http://gltrs.grc.nasa.gov>

The Fluids and Combustion Facility: Enabling the Exploration of Space

Karen J. Weiland, Frank G. Gati, Myron E. Hill, and Terence F. O'Malley
National Aeronautics and Space Administration
Glenn Research Center
Cleveland, Ohio 44135

Robert L. Zurawski
National Aeronautics and Space Administration
Johnson Space Center
Houston, Texas 77058

Abstract

The Fluids and Combustion Facility (FCF) is an International Space Station facility designed to support physical and biological research as well as technology experiments in space. The FCF consists of two racks called the Combustion Integrated Rack (CIR) and the Fluids Integrated Rack (FIR). The capabilities of the CIR and the FIR and plans for their utilization will support the President's vision for space exploration. The CIR will accommodate physical research and technology experiments that address needs in the areas of spacecraft fire prevention, detection and suppression, incineration of solid wastes, and power generation. Initial experiments will provide data to support design decisions for exploration spacecraft. The CIR provides a large sealed chamber in a near-weightless environment. The chamber supports many simulated atmospheres including lunar or Martian environments. The FIR will accommodate experiments that address needs for advanced life support, power, propulsion, and spacecraft thermal control systems. The FIR can also serve as a platform for experiments that address human health and performance, medical technologies, and biological sciences. The FIR provides a large volume for payload hardware, reconfigurable diagnostics, customizable software, active rack-level vibration isolation, and data acquisition and management in a nearly uniform temperature environment.

Introduction

In January 2004, President George W. Bush outlined an exciting new space exploration vision for NASA. The exploration programs will seek answers to profound questions of our origins, whether life exists beyond Earth, and how we could live on other worlds. The Fluids and Combustion Facility (FCF) is an International Space Station (ISS) facility designed to support physical and biological research as well as technology experiments in space that will support the new vision for space exploration. The FCF

consists of two modular, reconfigurable racks: the Combustion Integrated Rack (CIR) and the Fluids Integrated Rack (FIR), as shown in figures 1 and 2. The racks will be in the U.S. Laboratory Module and will operate primarily by telepresence with only reconfiguration and maintenance performed by the crew.

The CIR will accommodate experiments that address critical needs in the areas of spacecraft fire prevention, detection and suppression, incineration of solid wastes, and power generation. Initial experiments will provide data to support design decisions for exploration spacecraft. The CIR provides a large environmental chamber in which the space environment or lunar, Martian, or other planetary surface environments may be simulated. It can also serve as a test bed to mature systems and concepts to high technology readiness levels for exploration missions.

The FIR will accommodate payloads that address critical technology development and maturation needs for advanced life support (i.e., air revitalization, water reclamation, etc.), power, propulsion, and spacecraft thermal control systems. Payloads addressing boiling/condensation heat transfer, liquid vapor interface control, liquid/vapor evaporation/condensation, and multiphase flow, as they relate to the technology needs of various exploration spacecraft subsystems, will be the focus of investigations. The FIR provides a large, contiguous volume of about 0.5 cubic meter for experimental hardware, easily reconfigurable diagnostics, customizable software, active rack-level vibration isolation, data acquisition and management, and various other subsystems that will support a wide range of uses. It can also serve as a platform for experiments that address human health and performance, medical technologies, and biological sciences.

Common Rack Components

This section describes the subsystems common to both FCF racks. The use of common hardware reduces the design, development and life cycle costs, increases crew



Figure 1.—The Fluids and Combustion Facility Combustion Integrated Rack. At the top is the Fuel/Oxidizer Management Assembly, in the center is the combustion chamber, and at the bottom are the Electrical Power Conversion Unit (left) and Input/Output Processor (right).

efficiency by using common procedures, and allows for common sparing on orbit. (The sections on each individual rack describe the subsystems unique to each one.)

International Standard Payload Rack

The International Standard Payload Rack (ISPR) provides the supporting and mounting elements for the CIR and FIR subsystems and mechanical connections to the U.S. Laboratory Module. A set of slides mounted on the vertical sides of the rack provides attachment for an optics bench. The optics bench can translate out and rotate down for access to both sides as shown in figure 3. Both racks provide bi-fold doors with upper and lower halves. They provide acoustical, optical, and thermal isolation between the racks and the environment of the U.S. Laboratory Module. The doors contain six replaceable panel windows. The doors are closed during powered operations.

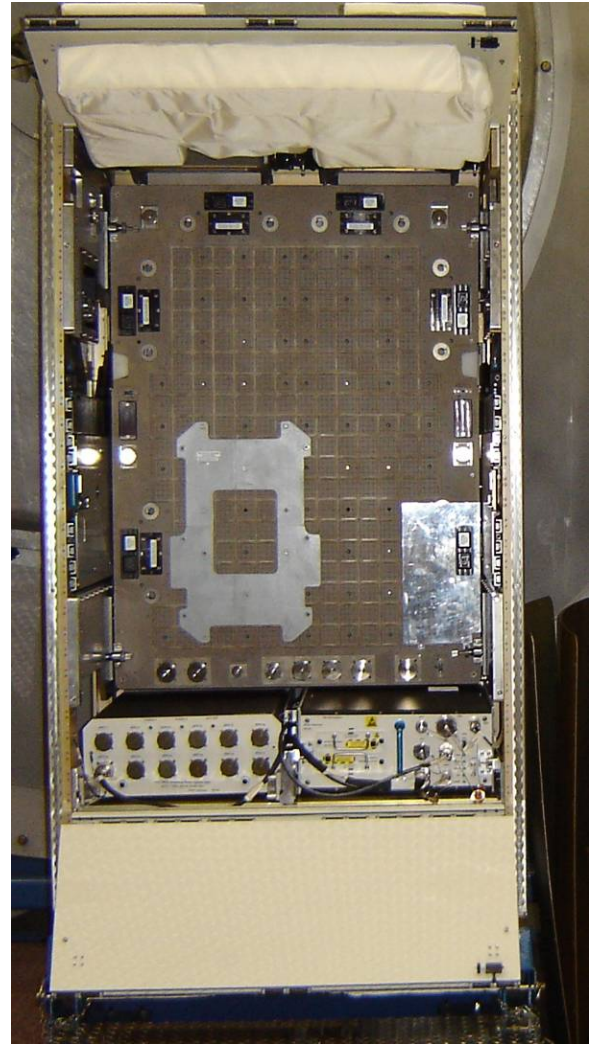


Figure 2.—The Fluids and Combustion Facility Fluids Integrated Rack. In the center is the optics bench and at the bottom are the Electrical Power Conversion Unit (left) and Input/Output Processor (right).

Electrical Power System

The Electrical Power Conversion Unit (EPCU) functions as the main power conditioning unit and power supply for each rack. The EPCU takes the 120 VDC power provided by the ISS and converts it to the 28 VDC required by most FCF packages. In addition, it makes available 120 VDC for the Fire Detection and Suppression System smoke detector, the Active Rack Isolation System controller, and, if it is required, to the sub-rack experiment. A total of 1600 W is available at 28 VDC and 1450 W at 120 VDC.

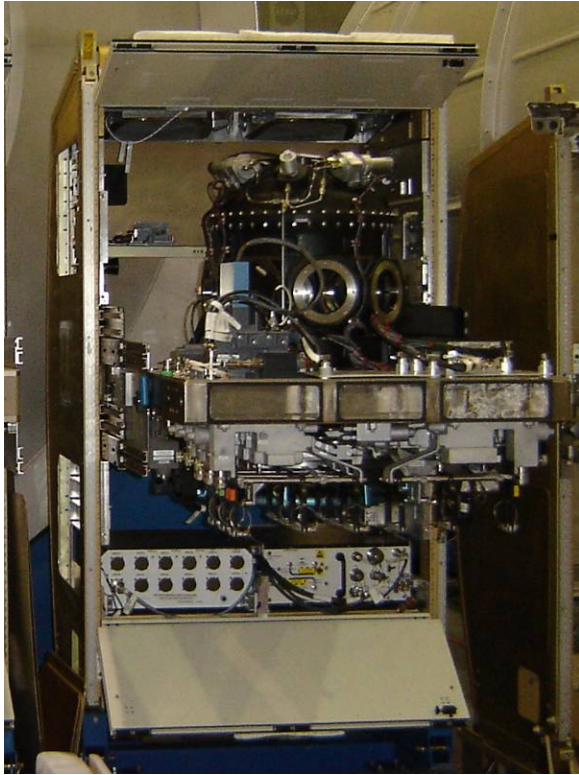


Figure 3.—The Combustion Integrated Rack with the optics bench translated and rotated. Visible on the back of the optics bench is the combustion chamber.

Environmental Control Subsystems

The FCF provides environmental control subsystems (ECS) that remove heat, provide fire detection and suppression, and provide interfaces to the ISS-supplied gases and vacuum vent lines.

The Water Thermal Control System (WTCS) provides water-cooling of all FCF equipment by removing their heat and transferring it to the ISS Internal Thermal Control System Moderate Temperature Loop. The WTCS provides cooling to the Air Thermal Control Unit (ATCU) and other FCF hardware in the primary loop. A secondary loop may cool payload hardware as required. Flexible hoses with quick disconnects allow for reconfiguration. The WTCS can remove up to 3000 W of waste thermal energy.

The ATCU resides in the top of each rack. It contains an air/water heat exchanger and two fans that circulate cooling air to the rack packages. In the CIR, the fans draw warm air from the rear of the rack and push it through the heat exchanger into the optics bench. In the FIR, the fans draw air from the optics bench in the rear of the rack and push it through the heat exchanger into the front of the rack. The ATCU can remove up to 1650 W of waste thermal energy.

The Fire Detection and Suppression System provides detection and suppression in case of fire in the rack. The ATCU provides rack air circulation past an ISS smoke detector. The ISS shuts off power to the rack if the detector triggers. Then, if required, a crewmember could discharge an ISS Portable Fire Extinguisher containing carbon dioxide into a hole on the front panel of the rack to extinguish any fire.

The Gas Interface Subsystem provides access to ISS-provided gaseous nitrogen and Vacuum Exhaust and Resource Systems. Nitrogen gas is available up to 827 kPa (120 psia). The VES provides for removal of waste gases from the system. The VRS is a low-flow system used primarily to maintain rack sub-systems at a vacuum. The rack sub-systems or experiment gases must meet ISS-allowable limits for contaminants to be eligible for venting through the ISS vent line.

Avionics Subsystems

The CIR and the FIR use several common avionics subsystems: the Input/Output Processor (IOP), Image Processing and Storage Unit (IPSU), Diagnostic Control Module (DCM), and the Station Support Computer (SSC).

The IOP is the main processor within the CIR and the FIR. It provides rack-level health and status monitoring, command and data processing, data management, control functions, and time synchronization. The IOP provides communications with the ISS through Ethernet and low and high rate data lines. It stores data on two 180 GB removable hard drives prior to downlinking by the ISS. The IOP accepts commands from either the ground by uplink to the ISS, or from the SSC.

Either rack can use common IPSUs. The IPSU supports a variety of camera formats. Two models of the common IPSU are available: the C-IPSU and the C-IPSU-A. The C-IPSU supports image acquisition from high-speed digital and IEEE 1394 (Firewire). The C-IPSU-A supports image acquisition from IEEE 1394 or analog video. In the CIR, two IPSUs can be stacked at certain mounting locations on the optics bench. Both types of IPSUs have two 36 GB hard drives and provide analog video output for experiment monitoring.

The DCM is a package module that provides power and control signals to the imaging portion of a camera package, or to an illumination package. It mounts on the optics bench.

The SSC is a laptop computer supplied by the ISS that connects to the IOP. It mounts on the front of the rack. The SSC allows the crew to view all science, health and status, and command screens. The crew can use the SSC to communicate with the FCF racks.

Space Acceleration Measurement System

A Space Acceleration Measurement System (SAMS) triaxial sensor head measures the microgravity acceleration

environment in the rack at its location on the optics bench. In the CIR, it mounts on the front near the combustion chamber. In the FIR, SAMS can be located anywhere in the payload working volume. This allows payloads to place the SAMS unit close to the area of interest. SAMS can measure microgravity accelerations from 1×10^{-6} to 0.01 g and provide three orthogonal measurements from 0.01 to 200 Hz. SAMS sends the data to the IOP, which then downlinks it as part of the telemetry. The Principal Investigator Microgravity Services (PIMS) team located at NASA Glenn extracts the SAMS data and provides it to the experiment team.

Software

The FCF makes extensive use of software because it is designed to operate primarily without crew involvement using telescience. The Telescience Support Center (TSC) at the NASA Glenn Research Center will support flight and some ground operations. The software accommodates new hardware and software upgrades. It is modular to minimize the amount of new software required for a new configuration. The ground operators can modify the flight software by uplinking new software from the ground.

The FCF flight software performs command and data processing, control, caution and warning, health and status monitoring, and timing functions. The operating system is VxWorks®. Programming languages are C++ and Java. Common subsystems software interacts with the IOP, ECS, C-IPSU, C-IPSU-A, DCM, and SSC. Packages unique to the CIR or the FIR have rack-specific software written for them.

The FCF ground software performs commanding of the flight unit, and receiving and viewing telemetry. FCF sends much of the data to the Earth via downlinking. The TSC receives and processes the payload data, and provides it to the experiment team, who can then use it to plan further experiment operations. The FCF operators at the TSC will have operator interfaces to display health and status, data, command and control, crew display, operator logs, and reporting. The TSC will archive the data for a ten-year period. Ground support units, crew trainers, and simulators also use ground software.

CIR Components

The CIR contains most of the hardware and software necessary for conducting combustion experiments. It will accommodate a range of combustion experiments while meeting the ISS requirements and limitations such as safety, power and energy, cooling, mass, crew time, stowage, resupply flights, and data downlink. The major subsystems of the CIR are the ISPR, Passive Rack Isolation System, optics bench, combustion chamber, diagnostics, fuel/oxidizer management assembly, environmental control subsystems, electrical power system, avionics subsystems,

flight and ground software, and interfaces for experiment-specific hardware. The previous sections described the common subsystems.

Each investigation will customize the facility with experiment packages that contain a small amount of hardware and software. The CIR design allows for the removal and replacement of different experiment packages within the combustion chamber. A replaceable Principal Investigator (PI) Avionics box mounts on the optics bench and provides for PI command and control of the experiment.

Passive Rack Isolation System

The ISPR contains a Passive Rack Isolation System (PaRIS) to isolate it from ISS and U.S. Laboratory vibrations. PaRIS isolates an entire ISPR. The PaRIS system provides passive attenuation by eight spring-damper isolators. The acceleration environment provided by PaRIS is frequency dependent, but for frequencies between 0.01 and 10 Hz, a model predicts that PaRIS will limit accelerations in the CIR to the micro-g level (ref. 1). This prediction used a conservative model in which all potential disturbers are active. Further reduction of the microgravity environment beyond that possible by PaRIS may be accomplished through operational planning to limit the potential disturbers active during the experiment operation time.

Optics Bench

The optics bench provides structural support, electrical connections, and mounting locations for other hardware, such as a chamber, gas handling system, and diagnostics. It spans two-thirds of the rack vertically and mounts on slides so that it slides out from the rack and folds down for access to both sides. The wiring harnessing and cooling airflow are internal to the bench. Diagnostics are interchangeable via a quick-latch mechanism at any of eight universal mounting locations around the combustion chamber. These locations provide air-cooling, electrical power, and communication and data interfaces.

Combustion Chamber

The combustion chamber is a cylindrical pressure vessel with domed end caps that mounts centrally to the optics bench. It has a volume of 100 liters and an internal diameter of 0.40 m and a length of 0.78 m. The front lid opens for on-orbit access to the inside of the chamber. The chamber has eight replaceable windows. The first launch set is made of sapphire. The chamber has a maximum design pressure differential of 827 kPa (120 psia). Four pressure transducers provide for pressure measurements. Electrical, vacuum, gas, venting, and other resources connect through an interface resource ring near the front of the chamber.

Chamber Insert Assembly

An experiment connects its hardware to the chamber by a chamber insert assembly (CIA), as shown in figure 4, which mounts on guide rails in the chamber. The chamber insert assembly is a framework for the mounting of internal components such as a burner, a nozzle, or a sample holder, diagnostic sensors, flow tunnel, and interface hardware. Its maximum length is 0.60 m long if the chamber mixing fan is present. The experiment team supplies the CIA.

Diagnostics

The diagnostics measurement systems perform the required and desired measurements of the combustion phenomena. Some of these are imaging systems that include the imaging device, an illumination source, and an image-processing package. Digital imaging systems provide for data fidelity and ease in data transfer and storage.

The diagnostics measurements segment into two categories. The CIR provides one set entirely, including the measurement device, power, control, and data collection and storage. These include visible and ultraviolet imaging, pressure measurement, gas composition, and accelerometry. The experiment team and the CIR jointly provide the other set of diagnostics. The diagnostics may include infrared and color imaging, temperature measurements, and flame radiation.

The diagnostic devices provided by the CIR are the High-Bit Depth Multispectral Imaging Package (HiBMs), the Illumination Package, and the Low-Light Level Ultraviolet Imaging Package (LLL-UV). The HiBMs consists of a telecentric optical system and a high resolution, 12-bit digital camera. The initial use of the HiBMs is for viewing backlit droplet images. A tunable liquid crystal spectral filter in conjunction with the Illumination Package allows for soot volume fraction and soot temperature measurements. The Illumination Package provides an illumination source to the chamber that consists of a collimated optical system and two identical light-emitting diode sources. The initial use of the Illumination Package is as a backlight source for the viewing of droplet images. The LLL-UV provides images of flames or objects at low radiance levels. The LLL-UV has an intensifier with a spectral range of 280 to 700 nm coupled to a monochrome camera. A filter at 310 nm provides for imaging of OH emission from flames.

Other sections discuss pressure measurements, gas composition, and accelerometry.

Fuel/Oxidizer Management Assembly

The Fuel/Oxidizer Management Assembly (FOMA) provides gaseous fuels, oxidizers, and diluents to the combustion chamber. The FOMA also provides gas sampling and analysis of the chamber contents, and cleanup

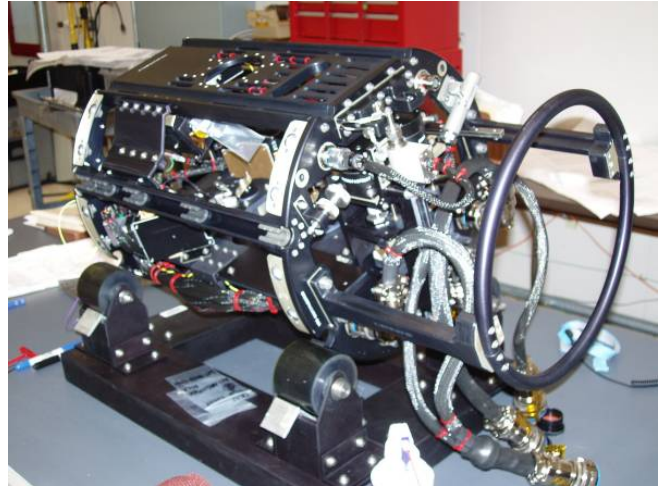


Figure 4.—This chamber insert assembly is used for studying flame suppression with droplet combustion.

and venting to space through the ISS vacuum exhaust system.

The gas delivery system contains gas supply bottles, valves, pressure regulators and switches, and mass flow controllers. The gas bottles may be 1.0, 2.25, or 3.8 liters and mount on the front of the optics bench for easy replacement by the crew. Up to four bottles may be used at one time. The maximum mole fraction of oxygen allowed in the bottle depends on its size: 1.0 liter up to 80 percent O₂, 2.25 liters up to 50 percent O₂, and 3.8 liters up to 30 percent O₂. The maximum oxidizer flow rate is 30 standard Liters per minute (slpm) per manifold for a total of 90 slpm (using three manifolds); maximum fuel flow rate is two slpm for propane. The gas delivery system performs on-orbit gas mixing by either partial pressure or by dynamic blending in the chamber.

A gas chromatograph (GC) analyzes the chamber contents. The GC is a repackaged commercial unit with three independent column modules that use helium and argon carrier gases. Two 500 mL bottles, which are changeable by the crew, contain the carrier gases. The GC can detect oxygen, inerts such as nitrogen or helium, fuels such as hydrogen, methane, methanol, and propane, and combustion products such as carbon dioxide, carbon monoxide, benzene, and formaldehyde at compositions ranging from 0.1 to 100 percent. The GC is not planned for use at initial installation of the CIR in ISS.

A filter cartridge removes particulates, water, and other contaminants from the gas to condition it for the next test point or prior to venting. One of two recirculation pumps pulls the gas through the recirculation loop at a rate of up to 9 slpm. Each experiment customizes the adsorber cartridge, which may contain substances such as lithium hydroxide, activated carbon, silica gel, and molecular sieve. A mass flow controller controls the rate at which gas vents. An

oxygen sensor measures the concentration of oxygen in the vent line. The FOMA system will not vent unless the oxygen concentration is less than 28 percent. A dew point sensor also assures that the level of water in the vented gas stream is acceptable.

FOMA Control Unit

The FOMA Control Unit (FCU) controls the FOMA components in the CIR. It monitors and stores all pressures, temperatures, and mass flow rates during gas blending and experiment operations, controls the GC for chamber sampling, and monitors the status of all FOMA hardware for transmittal to the ground via the IOP. The FCU commands set points of devices such as valves and mass flow controllers.

Principal Investigator Avionics Box

The optics bench contains a mounting location for the Principal Investigator (PI) Avionics Box. The experiment team designs the box, which communicates to the IOP and the chamber insert assembly. It will typically contain circuit boards, power supplies, software, and other avionics that the CIR does not supply.

FIR Components

The FIR provides the necessary hardware and capabilities for conducting technology development and maturation experiments on-board ISS in support of space exploration in areas such as advanced life support, power and propulsion. Its flexible volume and interfaces can accommodate a wide range of payloads while meeting the ISS requirements and limitations such as safety, power, cooling, mass, crew time, stowage, resupply flights, and downlink. The major subsystems of the FIR are the ISPR, Active Rack Isolation System (ARIS), optics bench, diagnostics, data acquisition and control, environmental control, electrical power, flight and ground software, and interfaces for payload-specific hardware. As with the CIR, each payload can customize the facility with payload-provided hardware and software. The FIR design allows for payload-provided hardware on the front and back of the optics bench. FIR-provided hardware that is not being utilized can be removed if required and even replaced with payload-provided hardware.

Common subsystems are described earlier in this paper. The following sections describe the FIR unique subsystems.

Active Rack Isolation System

If required, the Active Rack Isolation System (ARIS) can be used to enhance the microgravity environment for payloads in the FIR. Mounted in the ISPR, ARIS minimizes vibratory transmissions to and from the rack. ARIS utilizes three accelerometers to measure the microgravity

environment in the rack. Based on the measured accelerations, the ARIS system, unlike CIR's PaRIS system, applies reactive forces, between the FIR and ISS, through eight actuators to minimize transmission of vibratory disturbances.

Optics Bench

The centerpiece of the FIR structural subsystem is the optics bench. The optics bench provides a mounting surface for FIR light sources and avionics packages on the back of the bench and for payload hardware on the front or back of the bench. Depending on the use of the FIR-provided hardware, the optics bench will be able to accommodate up to 300 kg of payload hardware and provides a front mounting surface of 1100 by 895 by 495 mm. The front of the optics bench provides T-Slots and 1/4-28 threaded holes for mounting of payload hardware. The T-slots enable precise mounting of payload hardware, including optical components.

The optics bench is designed so that, in the unpowered mode, it can be translated out of the rack and rotated forward, as shown in figure 5, to allow the crew easy access to hardware mounted on the back of the optics bench. During powered operations the FIR optics bench is in the stowed position and the rack doors are closed.

Diagnostics

FIR provides a color camera, Nd:YAG laser and white light source as part of the initial facility development.

The Color Camera is a 24 bit, 3-chip Charged Coupled Device (CCD) analog color camera as shown in figure 6. The camera has a one-third inch array with a pixel density of 768 by 484 pixels. The camera's frame rate is settable up to 30 frames per second (fps) and shutter speed is settable from 1/60 of a second down to 1/10,000 of a second. In auto shutter mode, shutter speeds down to 1/50,000 of a second can be achieved. The color camera has a small remote head, 32 mm wide by 40 mm high by 40 mm diameter, to facilitate camera integration in congested areas. The color camera utilizes a standard C-mount for lenses.

The White Light Package, shown in figure 7, is located on the back of the FIR optics bench. The package consists of two 50 W metal halide bulbs subassemblies. Each subassembly has a fiber optic quick disconnect for attachment of a fiber bundle.

Adjusting an aperture knob located on a subassembly will vary the light intensity delivered through the fiber bundle attached to that subassembly. While the FIR provides a fiber bundle with a lens attachment, payloads can provide a specialized fiber bundle such as a bundle incorporating a light panel or ring light. Fibers are routed to the front of the optics bench from the white light package on the back of the bench through the fiber feedthrough located on the side of the bench.

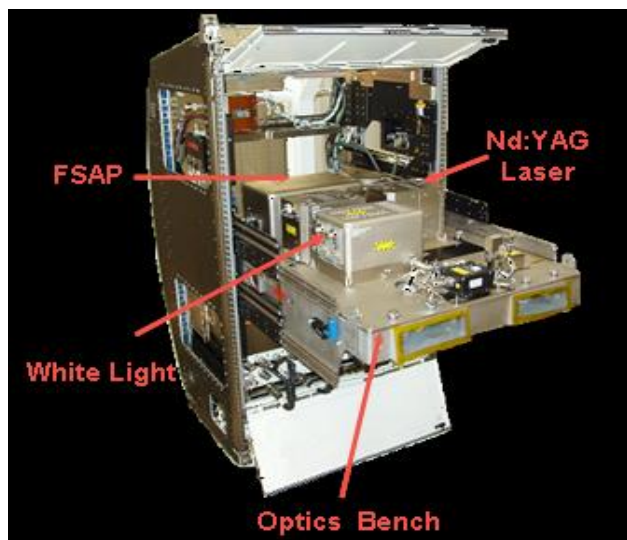


Figure 5.—The Fluids Integrated Rack with the Optics Bench translated and rotated. On the back of the bench are the White Light, Nd:YAG Laser, and the Fluids Science Avionics Packages.



Figure 6.—Color Camera Package. The Color Camera Controller is on the left and the Color Camera Photo Head is on the right.

The 532 nm Nd:YAG Laser Package, shown in figure 8, is located on the back of the FIR optics bench. When using the laser, a fiber optic cable from the laser is routed from the back of the bench through the fiber feedthrough to payload hardware on the front of the optics bench. A quick disconnect at the end of the fiber optic cable allows for easy hookup to payload hardware.

The laser is capable of providing a minimum power of 100 mW to the payload out of the FIR-provided fiber optic cable. The laser output power can be varied from 0 to 100 percent of the maximum power. A tap coupler located at the output of laser measures laser power delivered to the payload.

In addition to the FIR diagnostics discussed above, the CIR cameras can also be used in the FIR.



Figure 7.—White Light Package.



Figure 8.—Nd:YAG Laser Package.

Data Acquisition and Control

The Fluids Science and Avionics Package (FSAP) can provide the primary control in carrying out an experiment. Through the FSAP, the payload can execute an experiment by controlling the FIR diagnostics and avionics packages as well as payload hardware. Payload developers can download their own custom software into the FSAP for experiment control. The FSAP provides a standard set of computer data acquisition and control functions for use by the payload. The FSAP provides the following functions: motion control, analog to digital channels, digital to analog channels, digital inputs and outputs, external and internal triggers, RS-422, analog frame grabber and CAN bus. The FSAP has two 36 GB hard drives for storing analog and digital data, as well as analog video images captured by the analog frame grabber.

Development Status

NASA Glenn Research Center in Cleveland, Ohio is developing the FCF under a prime contract with ZIN Technologies, Inc. The overall system has concluded its flight hardware fabrication phase and package-level testing, and is in the process of completing rack-level testing. Upon completion of the testing at NASA Glenn, the racks will be shipped to the NASA Kennedy Space Center for additional testing in the Payload Test and Checkout System (PTCS). The PTCS provides a final functional checkout of the rack-to-ISS interfaces, a check of the physical fit, and interface testing of the fluids, structure, communication, and command and data handling interfaces. The Multi-Purpose Logistics Module (MPLM) will contain the racks for launch. Several variables remain that will effect the ultimate FCF launch date, such as the Shuttle Return to Flight date, the revised ISS Assembly Sequence, ISS resources available to payloads, and the manifesting priority of the payload and its relevance to exploration research. The current schedules shows launch of the FCF in 2007.

Initial Experiments

Supporting the Exploration Vision

In support of the exploration vision, NASA realigned the microgravity research program to support the major milestones such as a human moon landing and establishment of a lunar exploration test bed. Recent agency emphasis is on developing experiment areas that more directly support the technological needs of NASA missions. The design and operation of exploration spacecraft and partial-gravity habitats present new challenges for combustion in the areas of fire safety, waste incineration, and power generation. A major goal of NASA's combustion research program is to support the exploration vision by gaining increased understanding and insight into the behaviors of microgravity and partial-gravity flames (ref. 2). The areas of emphasis for fluids physics include life support, power, propulsion, and thermal control systems. More specifically, research areas such as boiling/condensation heat transfer, liquid vapor interface control, and multiphase flow will be particularly applicable.

Combustion Research Utilization

The combustion areas of interest include but are not limited to spacecraft fire prevention, detection and suppression, incineration of solid wastes, and power generation. Near-term experiments will support the exploration vision.

When possible, similar investigations will fly at the same time to increase the use of common hardware and diagnostics. A set of multi-user chamber inserts will support

experiments in droplets and solid fuels. Commercial and international investigations will provide their own chamber inserts or other resources in exchange for using a NASA insert. Multiple flight investigations and one or more commercial investigations are currently planning to use the CIR over the first few years of operation. Several international investigations are at the conceptual stage.

The initial investigations will study the combustion of small, spherical, individual fuel droplets. They will demonstrate the use of the CIR and will use a common insert and similar measurements. They will determine the flammability of a fuel droplet in limiting atmospheres of oxygen. Solid fuel experiments will focus on the quantification of material flammability in low pressure, increased oxygen atmospheres. The fuels include wire insulation, advanced composites, packing foam, and materials for inflatable structures.

Fluids Research Utilization

The Fluids Integrated Rack (FIR) will support technology development and maturation to enable storage/transfer of two-phase fluids, characterize two-phase heat transfer for potential power systems, support development of multi-phase environmental controls for life support systems, and support human health in physiological/medical systems research to enable long term missions to the moon and Mars.

Initial investigations on FIR will study thin film heat transfer applicable to wickless heat pipes, packed bed reactors and condensing heat exchangers. Development and utilization of wickless heat pipes and condensing heat exchangers will reduce the mass and complexity of thermal control systems for space exploration. Development and utilization of packed bed reactors are essential for compact and reliable water recovery systems.

The flexibility of the FIR (i.e., large volume for experimental hardware, easily reconfigurable diagnostics, and customizable software) allows accommodation of such experiments, and even ones from other disciplines such as biotechnology. When possible, similar investigations will fly at the same time to increase the use of common hardware and diagnostics. One example is the Light Microscopy Module, which will be used to conduct a thin film heat transfer experiment and can also accommodate biology related experiments.

Summary

The Fluids and Combustion Facility (FCF) is an International Space Station facility designed to support physical and biological research as well as technology experiments in space. The FCF consists of two racks called the Combustion Integrated Rack (CIR) and the Fluids Integrated Rack (FIR). The CIR will accommodate experiments that address needs in the areas of spacecraft fire

prevention, detection and suppression, incineration of solid wastes, and power generation. Initial experiments will provide data to support design decisions for exploration spacecraft. The FIR will accommodate experiments that address needs for advanced life support, power, propulsion, and spacecraft thermal control systems. It can also serve as a platform for experiments that address human health and performance, medical technologies, and biosciences.

References

1. Just, Marcus, "Final CIR Microgravity Assessment for Verification Closeout, Rev. A," FTS-TM-029A, ZIN Technologies, Inc., Brook Park, OH, Nov. 8, 2004.
2. Ruff, Gary A., Urban, David L., and King, Merrill K., "A Research Plan for Fire Prevention, Detection, and Suppression in Crewed Exploration Systems," AIAA-2005-0341, 43rd Aerospace Sciences Meeting and Exhibition, Reno, NV, January 2005.

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.				
1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE December 2005		3. REPORT TYPE AND DATES COVERED Technical Memorandum
4. TITLE AND SUBTITLE The Fluids and Combustion Facility: Enabling the Exploration of Space			5. FUNDING NUMBERS WBS-22-101-58-64	
6. AUTHOR(S) Karen J. Weiland, Frank G. Gati, Myron E. Hill, Terence F. O'Malley, and Robert L. Zurawski				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration John H. Glenn Research Center at Lewis Field Cleveland, Ohio 44135-3191			8. PERFORMING ORGANIZATION REPORT NUMBER E-15291	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Washington, DC 20546-0001			10. SPONSORING/MONITORING AGENCY REPORT NUMBER NASA TM-2005-213973 IAC-05-A2.5.04	
11. SUPPLEMENTARY NOTES Prepared for the 56th International Astronautical Congress sponsored by the Japan Aerospace Exploration Agency, Fukuoka, Japan, October 17-21, 2005. Karen J. Weiland, e-mail: Karen.J.Weiland@nasa.gov, Frank G. Gati, e-mail: Frank.Gati-1@nasa.gov, Myron E. Hill, e-mail: Myron.E.Hill@nasa.gov, and Terence F. O'Malley, e-mail: TFOMalley@nasa.gov, NASA Glenn Research Center; and Robert L. Zurawski, e-mail: Robert.L.Zurawski@nasa.gov, NASA Johnson Space Center. Responsible person, Karen J. Weiland, organization code PTO, 216-433-3623.				
12a. DISTRIBUTION/AVAILABILITY STATEMENT Unclassified - Unlimited Subject Category: 37 Available electronically at http://gltrs.grc.nasa.gov This publication is available from the NASA Center for AeroSpace Information, 301-621-0390.			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) The Fluids and Combustion Facility (FCF) is an International Space Station facility designed to support physical and biological research as well as technology experiments in space. The FCF consists of two racks called the Combustion Integrated Rack (CIR) and the Fluids Integrated Rack (FIR). The capabilities of the CIR and the FIR and plans for their utilization will support the President's vision for space exploration. The CIR will accommodate physical research and technology experiments that address needs in the areas of spacecraft fire prevention, detection and suppression, incineration of solid wastes, and power generation. Initial experiments will provide data to support design decisions for exploration spacecraft. The CIR provides a large sealed chamber in a near-weightless environment. The chamber supports many simulated atmospheres including lunar or Martian environments. The FIR will accommodate experiments that address needs for advanced life support, power, propulsion, and spacecraft thermal control systems. The FIR can also serve as a platform for experiments that address human health and performance, medical technologies, and biological sciences. The FIR provides a large volume for payload hardware, reconfigurable diagnostics, customizable software, active rack-level vibration isolation, and data acquisition and management in a nearly uniform temperature environment.				
14. SUBJECT TERMS International Space Station; Research facilities; Fluids; Combustion; Fire prevention; Biotechnology; Space exploration			15. NUMBER OF PAGES 15	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT	

